

Contents

SUMMARY	1
1 A PROGRAM OF RESEARCH INITIATIVES. . .	7
The Nature of the Field, 7	
Organization of the Report, 8	
Introduction to the Research Initiatives, 9	
Initiative in Atomic Physics, 10	
Fundamental Tests and High-Precision Techniques, 10	
Many-Electron Dynamics, 14	
Transient States of Atomic Systems, 16	
Initiative in Molecular Physics, 18	
The Physics of Isolated Molecules, 18	
The Physics of Molecular Collisions, 22	
Initiative in Optical Physics, 23	
New Light Sources, 24	
Advanced Spectroscopy, 26	
Quantum Optics, 28	
2 ATOMIC, MOLECULAR, AND OPTICAL PHYSICS	
IN THE UNITED STATES TODAY	29
Demographics of Atomic, Molecular, and Optical	
Physics, 29	

Size of the Field, 29	
Employment, 30	
Distribution of Effort, 30	
The Educational Role of Atomic, Molecular, and Optical Physics, 30	
Scientific Interfaces and Applications, 31	
The Economic Impact of Atomic, Molecular, and Optical Physics, 33	
The Health of the Field in the United States, 35	

3 RECOMMENDATIONS 37

Background—The History of Support, 37	
Comments, 38	
A Plan of Action, 43	
Recommendations, 45	
Base Support, 45	
Instrumentation, 46	
Theory, 47	
Access to Large Computers, 47	
Special Facilities, 48	
Accelerator-Based Atomic Physics, 48	
Atomic, Molecular, and Optical Physics with Synchrotron Radiation, 49	
Relevance of Atomic, Molecular, and Optical Research to the Funding Agencies, 50	
Department of Defense, 50	
Department of Energy, 51	
National Science Foundation, 51	
National Aeronautics and Space Administration, 52	

4 ATOMIC PHYSICS 53

Elementary Atomic Physics, 53	
Advances in Quantum Electrodynamics, 54	
Magnetic Moment of the Electron and Positron, 55	
Lamb Shift of Hydrogen, 57	
Muonium and Positronium, 57	
Muonic and Hadronic Atoms, 58	
Time-Reversal Symmetry, 58	

Neutral-Current Parity Violations in Atomic
Physics, 59

Foundations of Quantum Theory: Is Quantum
Mechanics Complete? 60

Studies of Time and Space, 61

Future Directions, 62

Atomic Structure, 63

Loosely Bound Atomic States, 63

Atoms in Strong Fields, 66

Double-Well Atomic Potentials, 67

Collective Atomic States, 67

Relativistic and Quantum Electrodynamic Effects in
Atoms, 68

Atomic Dynamics, 70

Structure of the Electron Continuum, 70

Dielectronic Recombination, 73

Ultralow Collisions, 74

Collisions with Rydberg Atoms, 75

Approximate Conservation Laws, 76

Toward the Complete Scattering Experiment, 77

Comparisons of Positron and Electron Scattering, 77

Accelerator-Based Atomic Physics, 78

Atomic Coherence and Out-of-Round Atoms, 79

Quantum Electrodynamics of Highly Charged
Systems, 79

Pair Production in Transient Superheavies, 80

Inner-Shell Molecular Orbitals and Molecular
Orbital X Rays, 81

Charge Transfer, 81

Slow-Recoil Ion Production, 82

Tunable X Rays, 83

Atomic Physics Requiring Larger Facilities, 83

Accelerator-Based Atomic Physics, 83

Atomic, Molecular, and Optical Physics with
Synchrotron Radiation, 86

5 MOLECULAR PHYSICS. 88

The New Spectroscopy, 88

New Views of Electronic Structure,	89
Electronic-Structure Theory: <i>Ab Initio</i>	
Calculations,	92
Hydrogen-Bonded Molecules,	92
Vibrational Structure of Polyatomic Molecules,	93
Molecular Photoionization and Electron-Molecule	
Scattering,	94
Molecular Photoionization,	95
Molecular Autoionization Dynamics,	95
Shape Resonances in Molecular Fields,	96
Resonant Multiphoton Ionization,	97
Electron-Molecule Collisions,	98
Molecular Dynamics,	99
State-to-State Chemistry,	100
Radiative Collisions,	102
New Ways to Understand the Dynamics of	
Chemical Reactions,	103
Variational Transition-State Theory,	104
Quasi-classical Trajectory Calculations,	105
Approximate Quantum-Scattering Calculations,	105
Resonances in a Simple Reaction Complex,	105
Bond Breaking and "Half-Collisions,"	106
Reactions at Very Low Temperatures,	107
Some Novel Molecular Species,	107
Molecular Ions,	108
Van der Waals Molecules,	109

6 OPTICAL PHYSICS	110
Lasers—The Revolution Continues,	110
Excimers and Excimer Lasers,	113
Laser Spectroscopy,	114
Ultraprecise Laser Spectroscopy,	115
Ultrasensitive Spectroscopy,	115
Doppler-Free Laser Spectroscopy,	116
Laser Cooling,	117
Coherent Optical Transients,	117
Ultranarrow Optical Transitions,	119
Coherent Raman Spectroscopy,	119

Quantum Optics and Coherence, 120	
Photon Antibunching, 120	
Optical Bistability, 121	
Squeezed States, 122	
Rydberg Atoms and Cavity Quantum Electrodynamics, 123	
Femtosecond Spectroscopy, 124	
7 SCIENTIFIC INTERFACES.	126
Astrophysics, 126	
Atomic Processes, 128	
Rydberg Atoms, 128	
Interstellar Molecules, 129	
Astrophysical Chemistry, 130	
Cosmology, 130	
Space Physics, 131	
Condensed-Matter Physics and Materials Science, 132	
Light-Scattering Spectroscopy, 132	
Clusters, 134	
Ultranarrow Optical Transitions, 136	
Spin-Polarized Quantum Fluids, 136	
Surface Science, 138	
Molecular-Beam Surface Scattering, 138	
Metal Clusters, 139	
Studying Surfaces with Laser Light, 141	
The Role of Atomic, Molecular, and Optical Data in Surface Science, 142	
Plasma Physics, 143	
Atmospheric Physics, 144	
Nuclear Physics, 146	
Optical Studies of the Nucleus, 146	
Polarized Nuclear Sources, 149	
Dynamics at the Atom-Nuclear Frontier, 149	
8 APPLICATIONS OF ATOMIC, MOLECULAR, AND OPTICAL PHYSICS	151
Precision Measurement Techniques, 151	
Fusion, 155	

- Magnetic Confinement, 157
- Inertial Confinement, 158
- National Security, 159
- Fiber-Optics Communications, 162
- Manufacturing with Lasers, 164
- Materials Processing, 166
 - Laser-Induced Surface Chemistry, 166
 - Ion Implantation, 166
- Data-Base Services, 167
- Medical Physics, 169
 - Laser Surgery, 169
 - Magnetic-Resonance Whole-Body Imaging, 171

FURTHER READING 175

INDEX 177

